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G1N
Selected US specifications from IPC sub-class G01C

(54) Direction finder

(57) A direction finder includes a terrestrial magnetism sensor (2), a magnetization correction means (3, 4) for correcting the output (x, y) of the sensor (2) with a magnetic field component produced by the vehicle on which the sensor is mounted and a correction amending means (6) for amending a corrected output, the correction amending means (6) determining the co-ordinates (x_p, y_p) of a crossing point between a line extending perpendicularly from co-ordinates (x_{v1}, y_{v1}) corresponding to a correction produced by the magnetization correction means (3, 4) onto the perpendicular bisector (l) of a line connecting two co-ordinate points (x_n, y_n; x_1, y_1) obtained by the sensor (2) at different times with the vehicle having different orientations.

FIG. 6

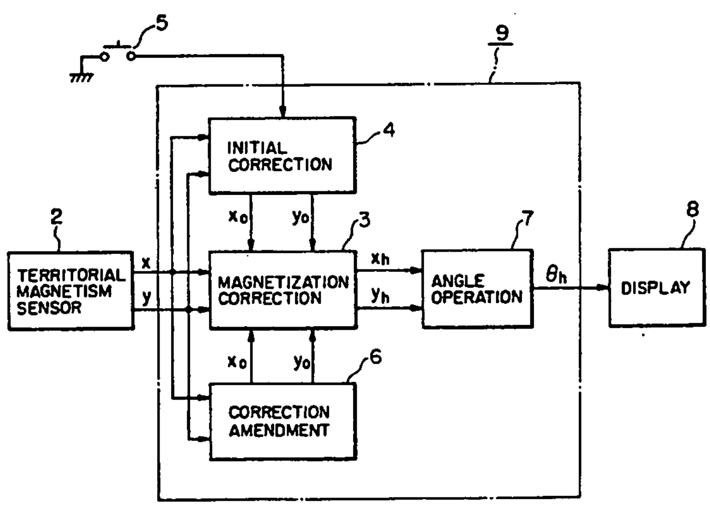
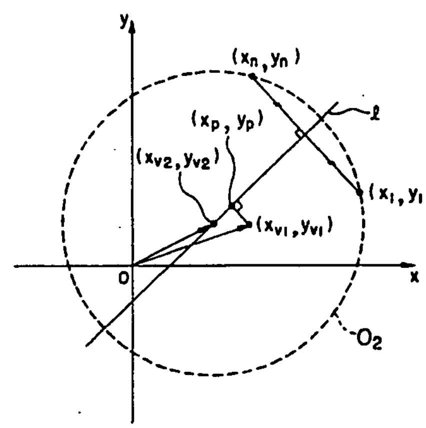


FIG. 7



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The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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FIG. 1

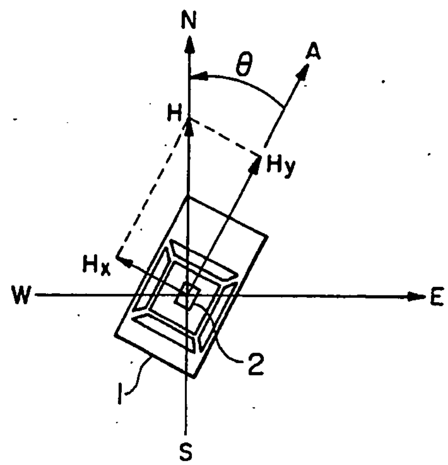

FIG. 2

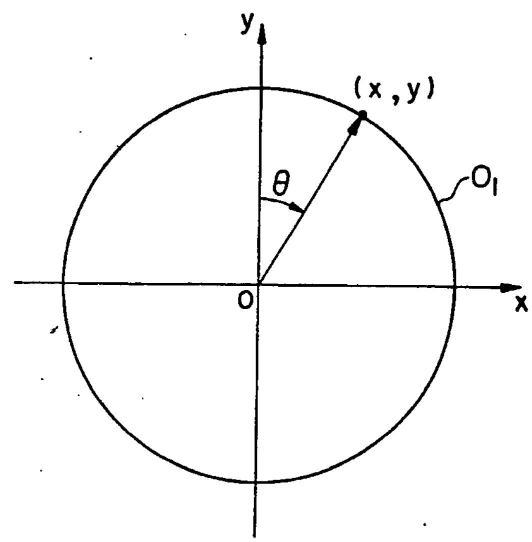

FIG. 3

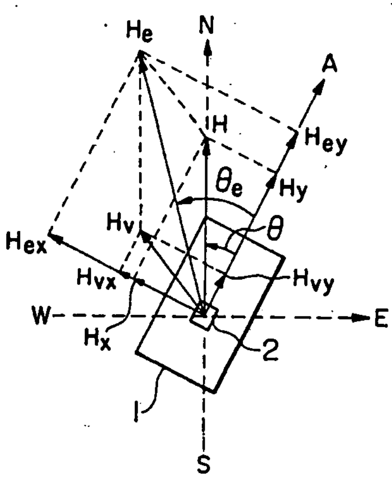

FIG. 4

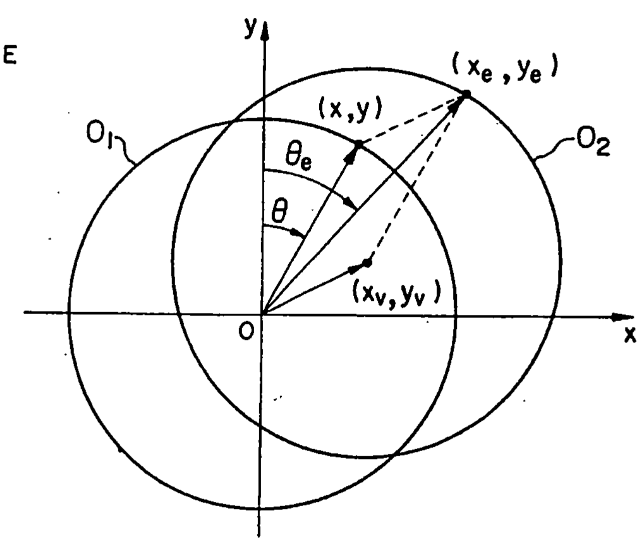

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FIG. 5

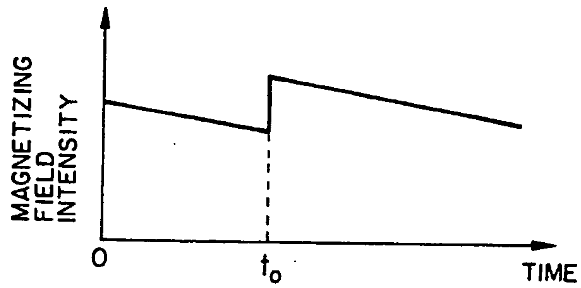

FIG. 6

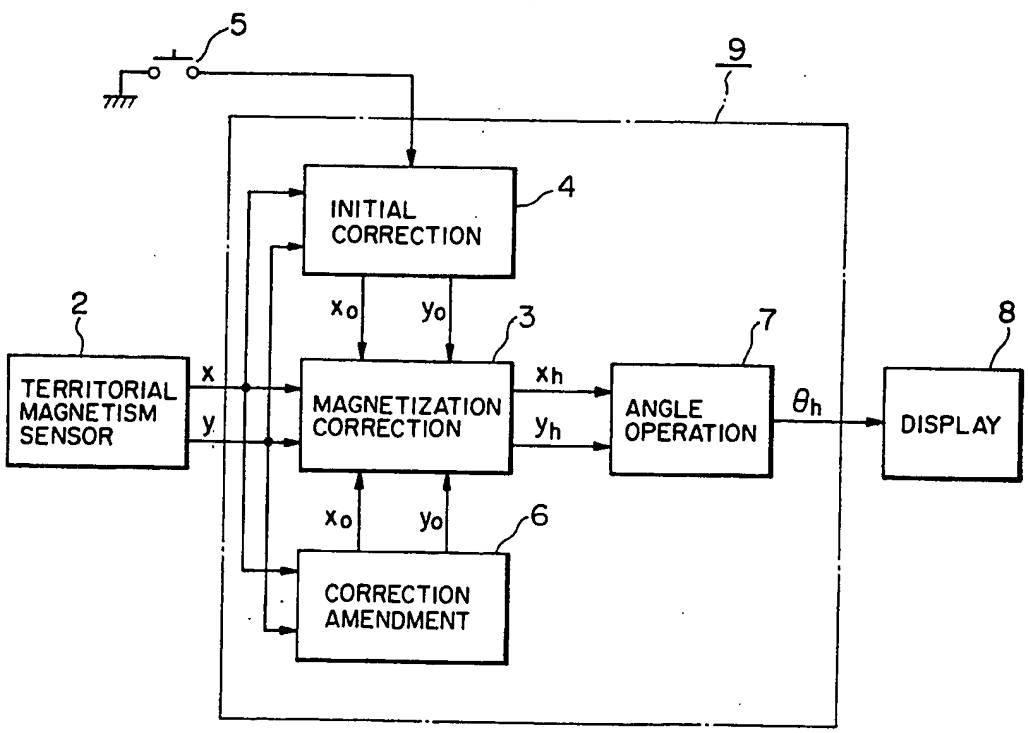

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FIG. 7

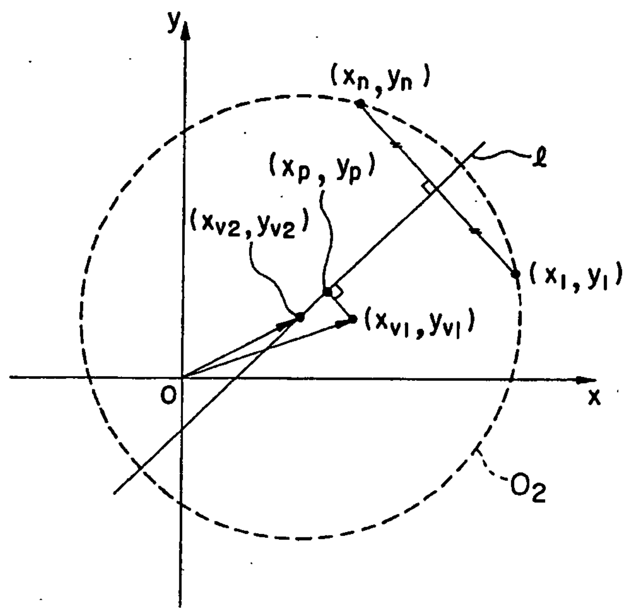


FIG. 8

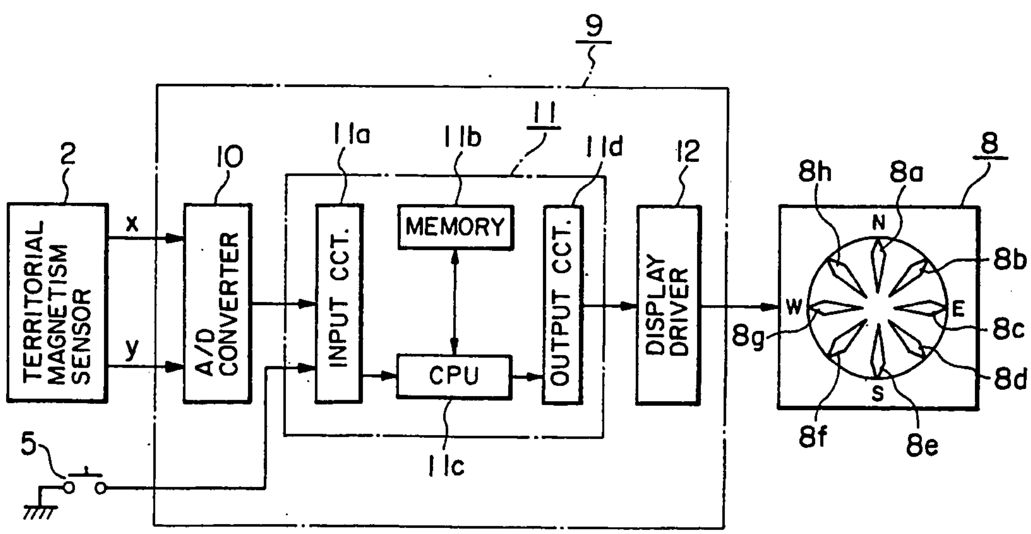


FIG. 9a

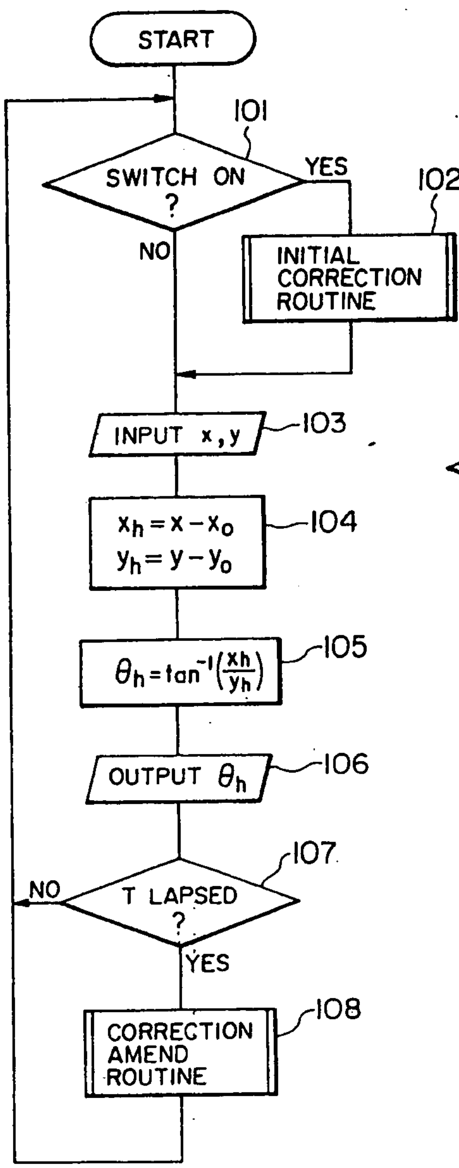

START
101
SWITCH ON ?
YES
NO
102
INITIAL CORRECTION ROUTINE
INPUT x,y
103
$x_h = x - x_o$
$y_h = y - y_o$
104
$\theta_h = \tan^{-1}\left(\frac{x_h}{y_h}\right)$
105
OUTPUT θ_h
106
107
T LAPSED ?
NO
YES
CORRECTION AMEND ROUTINE
108

FIG. 9b

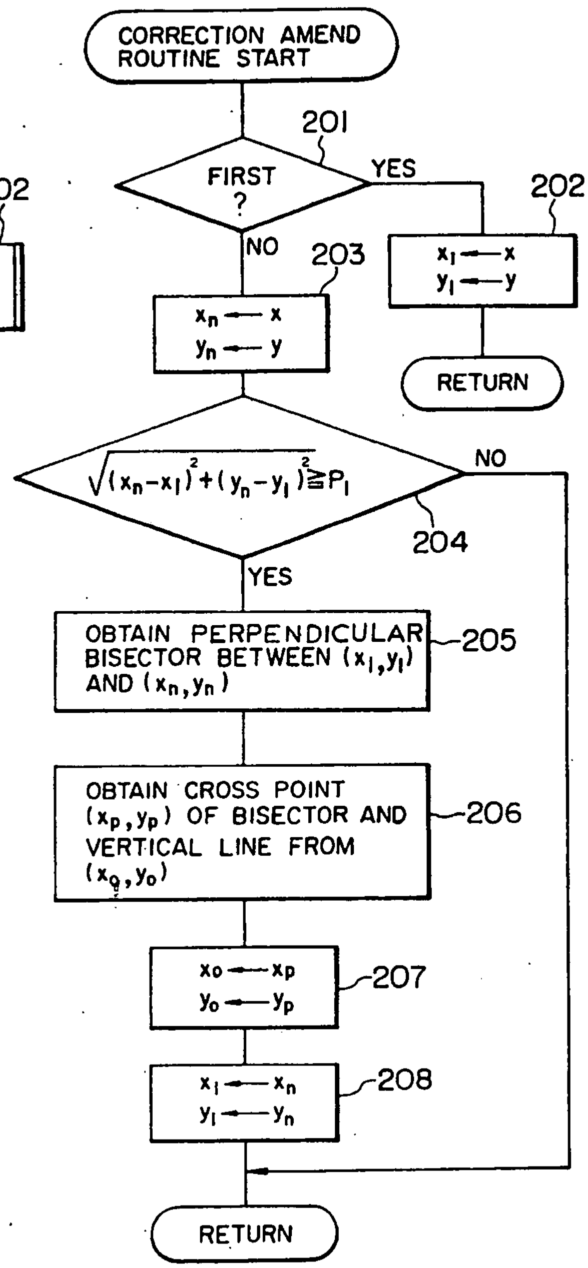
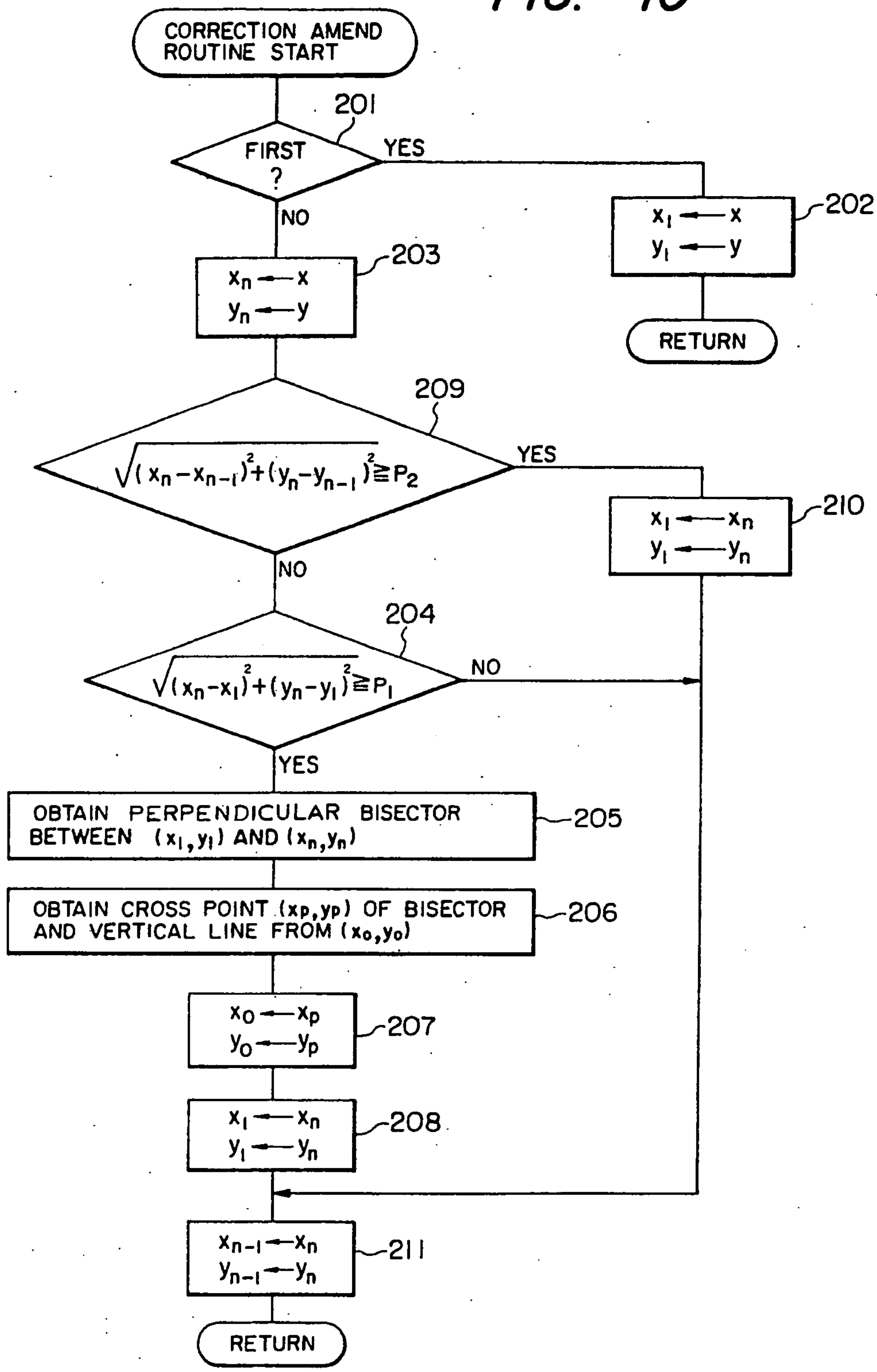

CORRECTION AMEND ROUTINE START
201
FIRST ?
YES
202
$x_1 \leftarrow x$
$y_1 \leftarrow y$
RETURN
NO
203
$x_n \leftarrow x$
$y_n \leftarrow y$
$\sqrt{(x_n-x_1)^2+(y_n-y_1)^2} \geqq P_1$
NO
204
YES
OBTAIN PERPENDICULAR BISECTOR BETWEEN (x_1,y_1) AND (x_n,y_n)
205
OBTAIN CROSS POINT (x_p,y_p) OF BISECTOR AND VERTICAL LINE FROM (x_o,y_o)
206
$x_o \leftarrow x_p$
$y_o \leftarrow y_p$
207
$x_1 \leftarrow x_n$
$y_1 \leftarrow y_n$
208
RETURN

FIG. 10


CORRECTION AMEND ROUTINE START
201
FIRST ?
YES
NO
202
$x_1 \leftarrow x$
$y_1 \leftarrow y$
RETURN
203
$x_n \leftarrow x$
$y_n \leftarrow y$
209
$\sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2} \geqq P_2$
YES
NO
210
$x_1 \leftarrow x_n$
$y_1 \leftarrow y_n$
204
$\sqrt{(x_n - x_1)^2 + (y_n - y_1)^2} \geqq P_1$
NO
YES
OBTAIN PERPENDICULAR BISECTOR BETWEEN (x_1, y_1) AND (x_n, y_n)
205
OBTAIN CROSS POINT (x_p, y_p) OF BISECTOR AND VERTICAL LINE FROM (x_o, y_o)
206
$x_o \leftarrow x_p$
$y_o \leftarrow y_p$
207
$x_1 \leftarrow x_n$
$y_1 \leftarrow y_n$
208
$x_{n-1} \leftarrow x_n$
$y_{n-1} \leftarrow y_n$
211
RETURN

SPECIFICATION

Direction finder

The present invention relates to a direction finder for use in a navigation system of a vehicle, which is capable of finding a moving direction of the vehicle on the basis of terrestrial magnetism.

There have been many navigation systems of this type and some will be described in detail subsequently with reference to the drawings. Such direction finders need correction to compensate for the magnetic influence of the vehicle on which the direction finder is mounted. At present none of the conventional direction finders make any allowance for the magnetic influence of the vehicle changing during operation.

According to this invention, a direction finder comprises a terrestrial magnetism sensor mounted on the vehicle for detecting a pair of orthogonal components of a horizontal component of terrestrial magnetism to provide a pair of detection signals corresponding to the orthogonal components, respectively; a magnetization correction means for correcting the pair of detection signals with a pair of correction values necessary to cancel out the influence of a magnetic field produced by the vehicle and providing a pair of corrected detection signals; and a correction amending means for obtaining the perpendicular bisector of a line connecting two co-ordinate points corresponding to the pair of detection signals from the terrestrial magnetism sensor and the pair of corrected detection signals from the magnetization correction means on a rectangular co-ordinate system and to amend the correction values on the basis of the co-ordinate components of a crossing point of the perpendicular bisector and a line extending perpendicularly from the perpendicular bisector to that crossing point.

A particular example of a direction finder in accordance with this invention, will now be described and contrasted with the prior art, with reference to the accompanying drawings, in which:

Figures 1 and 2 illustrate the operating principle of a direction finder with the assumption of the vehicle generating no magnetic field;

Figures 3 and 4 illustrate the operating principle of a conventional direction finder when the vehicle does generate its own magnetic field;

Figure 5 is a graph illustrating a variation of magnetic field with time;

Figure 6 is a block diagram of an example of the present invention;

Figure 7 is a graph illustrating the principle of operation of the present invention;

Figure 8 shows a block diagram of the example shown in Figure 6 in more detail;

Figures 9a and 9b are flow charts illustrating the operation of a micro-computer shown in Figure 8; and

Figure 10 is a flow chart showing an alternative operating strategy of the micro-computer.

In a typical conventional direction finder the horizontal component H of terrestrial magnetism, which is referred to as "terrestrial magnetism H" hereinafter, is detected by a terrestrial magnetism sensor 2 mounted on a vehicle 1, e.g. an automobile, whose heading makes an angle θ with respect to the direction of terrestrial magnetism H, i.e. north. That is, the sensor 2 detects a field component Hy (=H cos θ) of the magnetism H which is in parallel with the moving direction A of the vehicle 1 and a field component Hx (=H sin θ) orthogonal to the direction A and provides electric signals x and y in the form of, for example, voltages corresponding thereto. The electric signals x and y are amplified suitably. Thus, the electric signals x and y can be expressed by

$$x = K\,Hx = K.H \sin\theta \qquad \text{......(1a)}$$

$$y = K\,Hy = K\,H \cos\theta \qquad \text{......(1b)}$$

where K is a magnetism/voltage conversion co-efficient.

The detected signals x and y when the field components Hx and Hy are zero are calibrated to zero so that the magnitudes of the signals x and y are in proportion to the intensities of the components Hx and Hy, respectively and can be used as reference values.

Fig. 2 shows an x-y rectangular coordinates system on which points each defined by magnitudes of the electric signals x and y are plotted. A locus of the plot describes a circle O_1 and the angle θ, i.e., the orientation θ of the vehicle 1 is given by

$$\theta = \tan^{-1}(x/y) \qquad \text{..... (2)}$$

Although the direction of the terrestrial magnetism H is not coincident with the geographical

north and there is an error, i.e., declination therebetween. The declination depends on areas of the earth. It is assumed in this description, however, that there is no declination for simplicity of explanation.

It has been known that, due to magnetization of magnetic material of various components constituting the vehicle, the orientation θ calculated according to the equation (2) is not always correct.

Describing this in more detail with respect to Figs. 3 and 4, the vehicle 1 is subjected to a magnetic field Hv shown in Fig. 3 produced by those magnetized components. With the magnetic field Hv, the magnetic field to be detected by the terrestrial magnetism sensor 2 becomes a composite magnetic field He of the terrestrial magnetism H and the magnetic field Hv. Coordinates (x,y), (x_v,y_v) and (x_e,y_e) of signals from the sensor 2, corresponding to coordinates (Hx,Hy), (Hvx,Hvy) and (Hex,Hey), are shown in Fig. 4. Thus, the signals xe and ye from the sensor 2 are represented by

$$x_e = x + x_v = KH \sin \Theta + x_v \quad \ldots\ldots (3a)$$

$$y_e = y + y_v = KH \cos \Theta + y_v \quad \ldots\ldots (3b)$$

where the angle θ_e obtained from the signals x_e and y_e according to the equation (2) becomes

$$\Theta_e = \tan^{-1}(x_e/y_e) \quad \ldots\ldots (4)$$

Thus, a true orientation θ can not be obtained.

However, since the field Hv is produced by the vehicle 1 as a permanent magnet and an intensity and direction thereof with respect to the moving direction A of the vehicle 1 are constant, the coordinates (x_v,y_v) of the signal corresponding to the magnetic field Hv shown in Fig. 4 is kept unchanged even if the direction A is changed. Therefore, a locus of the coordinates (x_e,y_e) of the detection signal when the vehicle 1 runs once along a circle becomes a circle O_2 having a center point (x_v,y_v) as is clear from the equations (3a) and (3b). Therefore, by obtaining the center coordinates (x_v,y_v) of the circle O_2 from the detection signals x_e and y_e, the true orientation θ can be obtained easily from the following equation

$$\Theta = \tan^{-1}((x_e - x_v)/(y_e - y_v)) \quad \ldots\ldots (5)$$

Japanese Patent Application Laid-Open No. 148210/1982 discloses a technique by which the true orientation θ is obtained by cancelling out influences of the magnetic field Hv on the basis of the principle mentioned above. In detail, among the detection signals x and y obtained from the terrestrial magnetism sensor 2 when the vehicle 1 circles once, maximum values x_{max} and y_{max} and minimum values x_{min} and y_{min} in the respective axes of the x-y rectangular coordinates system are stored and the detection signals x_v and y_v corresponding to the magnetic field Hv is obtained as coordinates of the center of the circular locus O_2, according to the following equations

$$x_v = (X_{max} + x_{min})/2 \quad \ldots\ldots (6a)$$

$$y_v = (y_{max} + y_{min})/2 \quad \ldots\ldots (6b)$$

Therefore, by turning around the vehicle 1 in a suitable time to obtain the detection signals x_v and y_v corresponding to the magnetic field Hv, it is possible to obtain the true orientation θ by performing an operation of the equation (5).

However, when the vehicle 1 is, for example, an automobile, it is subjected to vibrations during its movement. Therefore, the magnetic field Hv may vary gradually as shown in Fig. 5, although the variation might be negligible when averaged over, for example, one day. In addition, when the automobile crosses a d.c. powered railway line at a time instance t_o, it may be magnetized by a magnetic field produced by a d.c. current flowing through the rails and cables and thus the intensity and direction of the field Hv are considerably changed. With such change of the field Hv, the automobile must circle again to obtain the signals x_v and y_v corresponding to the changed field Hv. This is very difficult practically.

An example of the present invention will be described with reference to Figs. 6 to 9a.

In Fig. 6, the navigation system includes a terrestrial magnetism sensor 2 which is identical to that shown in Fig. 1, a magnetization correction means 3 for correcting detection signals x and

y obtained by the terrestrial magnetism sensor 2 on the basis of a pair of correction amounts x_o and y_o by which an influence of a magnetic field Hv is cancelled out, according to the following equations

$$x_h = x - x_o \quad \text{.....} \ (7a)$$

$$y_h = y - y_o \quad \text{.....} \ (7b)$$

and providing a pair of corrected detection signals x_h and y_h, an initial correction means 4 which is actuated by operation of a switch 5 to detect and store the detection signals x and y upon a turning operation of a moving body 1, to obtain detection signals x_v and y_v corresponding to the magnetic field Hv according to the equations (6a) and (6b) and to set the values x_v and y_v to the correction values x_o and y_o for a subsequent use in the magnetization correction means 3, a correction amending means 6 responsive to the detection signals x and y from the sensor 2 for amending the corrected values x_o and y_o such that the values approach coordinates (x_v, y_v) on an x-y rectangular coordinate system corresponding to changed magnetic field Hv, an angle calculation means 7 responsive to the correction detection signals x_h and y_h from the magnetization correction means 3 to operate an orientation θh according to

$$\theta = \tan^{-1}(x_h/y_h) \quad \text{......} \ (8)$$

and a display means 8 for displaying the orientation θh from the angle calculation means 7. The components depicted by reference numerals 3, 4, 6 and 7 constitute a control means 9.

A principle of operation of the correction amending means 6 will be described with reference to Fig. 7. In Fig. 7, it is assumed that coordinates on the x-y rectangular co-ordinate system of the magnetic field Hv are represented by $(x_{v1}, y_{v1})$and (x_{v2}, y_{v2}), respectively, coordinates corresponding to the detection signal pair obtained after the magnetic field Hv1 varies to Hv2 are represented by (x_1, y_1) and (x_n, y_n), respectively, and values set in the correction values x_o and y_o of the magnetization correction means 3 before the field Hv changes are represented by x_{v1} and y_{v2}, respectively.

The perpendicular bisector ℓ of the line connecting between the coordinates (x_1, y_1) and (x_n, y_n) corresponding to the detection signals obtained after the field Hv1 is changed to Hv2 passes, necessarily, through the coordinates (x_{v2}, y_{v2}) corresponding to the field Hv2 and representing a coordinates of a cross point of the line ℓ and a perpendicular line extending from the coordinates (x_{v1}, y_{v1}) corresponding to the field Hv1 to the line ℓ by (x_p, y_p), the following equation (9) is established between the coordinates (x_{v1}, y_{v1}), (x_{v2}, y_{v2}) and (x_p, y_p).

$$(x_{v2}-x_p)^2 + (y_{v2}-y_p)^2 \leqq (x_{v1}-x_p)^2 + (y_{v1}-y_p)^2 \quad \text{....} (9)$$

Therefore, the coordinates (x_p, y_p) of the cross point becomes equal to or at least closer to the coordinates corresponding to the field Hv2 than the coordinates (x_o, y_o) corresponding to the correction amount before the magnetic field Hv is Hv1, i.e., the coordinates (x_{v1}, y_{v1}), thus, after the magnetic field is changed, the components x_p and y_p of the coordinates (x_p, y_p) of the cross-point are set as the correction amounts x_o and y_o. By repeating this operation, it is possible to proximate the correction amounts x_o and y_o to the components x_{v2} and y_{v2} corresponding to the magnetic field Hv2, i.e., the correction amounts necessary to cancel out the influence of the magnetic field Hv2.

Fig. 8 shows the embodiment in Fig. 6 in more detail in which same components are depicted by same reference numerals, respectively. In Fig. 8, the control means 9 comprises an A/D converter 10 for converting the detection signals x and y from the terrestrial magnetism sensor 2 into digital values, a microcomputer 11 composed of an input circuit 11a, a memory 11b, a central processing unit (CPU) 11c and an output circuit 11d and a display driver 12 responsive to an output of the computer 11 for driving the display 8. The display 8 which may include a liquid crystal display panel has display segments 8a to 8h which are driven by an output of the driver 12 to illuminate one at a time for displaying the orientation θh.

An operation of the computer 11 will be described with reference to the flow-charts shown in Figs. 9a and 9b.

In Fig. 9a, when a power source (not shown) is connected by operating the switch 5, the terrestrial magnetism sensor 2, the control circuit 9 and the display 8 begin to operate. That is, the sensor 2 starts to detect terrestrial magnetism H and provides detection signals x and y corresponding to the x and y components thereof which are A/D converted by the A/D

converter 10 and then the digitized signals are supplied to the computer 11.

The computer 11 performs a main routine starting from the step 101, as shown in Fig. 9a. In the step 101, it is determined whether or not the switch 5 is turned on. If yes, the initial correction routine is performed in the step 102 to obtain the correction amounts x_o and y_o.

An operation of the magnetization correction means 3 is shown in the steps 103 and 104. That is, the detection signals x and y are inputted in the step 103 and then the correction detection signals x_h and y_h are obtained according to the equations 7a and 7b in the step 104.

Then, the orientation θh is obtained according to the equation (8) in the step 105 and the signal θh is provided to the display driver 12 in the step 106. The steps 105 and 106 correspond to an operation of the angle calculation means 7. The display driver 12 drives the display 8 to cause it to display the orientation θh by illuminating a suitable one of the display segments 8a to 8h thereof.

Thereafter, within a predetermined period T, the routine is returned to the step 101 and the same operation is repeated until the time period T lapses.

When the time period T lapses while the operation of the magnetization correction means 3 is repeated through the steps 101 to 107, a correction amending routine is performed in the step 108, which is shown by the flow-chart in Fig. 9b.

In the correction amending routine, it is determined whether or not the execution of the routine is first time in the step 201. If yes, the detection signals x and y obtained in the step 103 are set as reference detection signals x_1 and y_1 in the step 202 and it is returned to the main routine shown in Fig. 9a.

When it is determined in the step 201 that the amending routine is used not firstly, newest detection signals x and y obtained in the step 103 are set as current detection signals x_n and y_n in the step 203. Then, in the step 204, it is determined whether or not a distance $\{(x_n-x_1)^2 + (y_n-y_1)^2\}^{1/2}$ between the coordinates corresponding to the current detection signals x_n and y_n and the reference detection signals x_1 and y_1, respectively, is equal to or larger than a first predetermined value p_1. If yes, the correction values x_o and y_o are amended through the steps 205 to 208. If no, it is returned to the main routine shown in Fig. 9a.

Describing the amending operation in more detail, the perpendicular bisector ℓ with respect to the coordinates (x_1,y_1) and (x_n,y_n) of the respective detection signals is obtained in the step 205.

Assuming that the perpendicular bisector ℓ is represented by

$$y = ax + b \quad \text{..... (10)}$$

The constants a and b are given by the following equations

$$a = (x_n - x_1)/(y_n - y_1) \quad \text{..... (10a)}$$

$$b = \{(x_1{}^2 + y_1{}^2) - (x_n{}^2 + y_n{}^2)\}/2(y_1 - y_n) \quad \text{.... (10b)}$$

Then, in the step 206, the coordinates (x_p,y_p) of the cross point of the bisector ℓ and a line extending perpendicularly from the coordinates (x_o,y_o) corresponding to the correction values x_o and y_o to the bisector is obtained.

The coordinates (x_p,y_p) is given by

$$x_p = \{x_o + a(y_o - b)\}/(a^2+1) \quad \text{..... (11a)}$$

$$y_p = ax_o + b \quad \text{..... (11b)}$$

When the coordinates components y_1 and y_n are equal to each other, the equation of the perpendicular bisector θ becomes

$$x = (x_1 + x_n)/2 \quad \text{..... (12)}$$

Therefore, the coordinates (x_p,y_p) is given by

$$x_p = (x_1 + x_n)/2 \quad \ldots\ldots (13a)$$

$$y_p = y_o \quad \ldots\ldots (13b)$$

Then, in the step 207, the components x_p and y_p of the coordinates (x_p, y_p) are set as the correction amounts x_o and y_o, respectively, and, after the correction signals x_n and y_n are set as the reference detection signals x_1 and y_1 in the step 208, it is returned to the main routine.

Therefore, when the orientation A of the vehicle 1 is changed during the movement thereof while the above operation is performed continuously, the amending operation of the correction values is performed through the steps 205 to 208, so that the correction amounts x_o and y_o approach the true correction amounts x_{v2} and y_{v2} required to cancel out the magnetic field Hv2. When the field Hv2 is further changed during the repetition of the above steps, the correction values x_o and y_o obtained as above also approach the true correction amounts required to cancel out the changed magnetic field. Therefore, in a case where the field Hv changes time to time, the correction amounts x_o and y_o can be amended automatically during a normal movement of the vehicle 1 without necessity of turning required in the step 102 of the initial correction routine. As a result, the correction detection signals x_h and y_h obtained in the step 104 always indicate a more precise orientation of the vehicle.

Fig. 10 is a flow chart showing another embodiment of the present invention, which is featured over the correction amending routine shown in Fig. 9b by a provision of the steps 209 to 211. In the step 209, it is determined whether or not a distance $\{(x_n-x_{n-1})^2 + (y_n-y_{n-1})^2\}^{1/2}$ between a coordinates (x_n, y_n) corresponding to a current detection signal and a coordinates (x_{n-1}, y_{n-1}) corresponding to a preceding detection signal is equal to or larger than a second predetermined value p_2. If yes, the current detection signals x_n and y_n are set as reference detection signals x_1 and y_1 in the step 210. If no, it goes on through the steps 204 to 208 identical to those in Fig. 9a, to set the current detection signals x_n and y_n as the preceding detection signals x_{n-1} and y_{n-1} in the step 211 for subsequent operation.

Accordingly, the embodiment in Fig. 10 provides the same effect as that obtained by the preceding embodiment and further provides an additional effect that, by judging the fact that the distance between the coordinates points changed during the period T to a value equal to or larger than the predetermined value p_2 is to indicate an occurrence of such abrupt change of magnetic field as shown in Fig. 5, an erroneous operation of the correction amounts x_o and y_o based on the detection signals x_1 and y_1 before the change of the magnetic field and the detection signals x_n and y_n after the change, i.e., the set of detection signal pairs the required correction amounts of which are different from each other is prevented.

In these embodiments described hereinbefore, the correction amounts x_o and y_o are amended when the distance between the coordinates (x_1, y_1) and (x_n, y_n) is equal to or larger than the predetermined value p_1 as in the step 204. The reason for this is to prevent an operation error of the perpendicular bisector from increasing substantially when the distance is too small and detection errors exist in the detection signals x_1 and y_1 and x_n and y_n.

Therefore, if such detection error is negligible, it may be possible to operate the correction values x_o and y_o on the basis of the preceding and current detection signals x_{n-1}, y_{n-1}, x_n and y_n, without using the step 204.

Although the present invention has been described with reference to the automobile as the vehicle, it may be any other vehicle such as ship and aircraft.

As mentioned hereinbefore, according to the present invention, the correction amounts for the changing magnetic field intensity can be amended automatically time to time to thereby obtain the precise correction to the magnetic field.

CLAIMS

1. A direction finder for use on a moving vehicle, comprising a terrestrial magnetism sensor mounted on the vehicle for detecting a pair of orthogonal components of a horizontal component of terrestrial magnetism to provide a pair of detection signals corresponding to the orthogonal components, respectively; a magnetization correction means for correcting the pair of detection signals with a pair of correction values necessary to cancel out the influence of a magnetic field produced by the vehicle and providing a pair of corrected detection signals; and a correction amending means for obtaining the perpendicular bisector of a line connecting two co-ordinate points corresponding to the pair of detection signals from the terrestrial magnetism sensor and the pair of corrected detection signals from the magnetization correction means on a rectangular co-ordinate system and to amend the correction values on the basis of the co-ordinate components of a crossing point of the perpendicular bisector and a line extending perpendicularly from the perpendicular bisector to that crossing point.

2. A direction finder according to claim 1, wherein the correction amending means amends the

correction values when the distance between co-ordinate points corresponding to a current detection signal pair from the terrestrial magnetism sensor and a preceding detection signal pair from the terrestrial magnetism sensor stored as a reference detection signal pair becomes equal to or larger than a first predetermined value.

3. A direction finder according to claim 1 or claim 2 wherein the correction amending means utilizes a current detection signal pair from the terrestrial magnetism sensor as a reference detection signal pair in obtaining the perpendicular bisector when the distance between co-ordinate points corresponding to the current detection signal pair and a detection signal pair obtained by the terrestrial magnetism sensor and stored at a predetermined time before the current detection signal pair was obtained is equal to or larger than a second predetermined value.

4. A direction finder according to any one of the preceding claims, wherein the magnetization correction means comprises an initial correction means responsive to an output of the sensor to obtain correction amounts and a correction means for correcting the pair of electric signals with the correction amounts obtained by the initial correction means and providing a pair of corrected signals.

5. A direction finder according to any one of the preceding claims, which also includes an angle calculation means responsive to an output of the magnetization correction means for calculating an angle between a moving direction of the vehicle and a direction of the horizontal component of terrestrial magnetism; and a display means for displaying the calculated angle.

6. A direction finder according to claim 5, wherein the magnetization correction means, the correction amending means and the angle calculation means constitute a control device and the control device comprises an A/D converter connected to an output of the terrestrial magnetism sensor, a micro-computer and a display drive connected to the display means.

7. A direction finder substantially as described with reference to the accompanying drawings.

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